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Searches for Λ_b^0 and Ξ_b^0 decays to $K_S^0 p \pi^-$ and $K_S^0 p K^-$ final states with the first observation of the $\Lambda_b^0 \rightarrow K_S^0 p \pi^-$ decay

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ABSTRACT

A search for previously unobserved decays of beauty baryons to the final states $K_S^0 p \pi^-$ and $K_S^0 p K^-$ is reported. The analysis is based on a data sample corresponding to an integrated luminosity of 1.0 fb^{-1} of pp collisions. The $\Lambda_b^0 \rightarrow K_S^0 p \pi^-$ decay is observed for the first time with a significance of 8.6σ , and a measurement is made of the CP asymmetry, which is consistent with zero. No significant signals are seen for $\Lambda_b^0 \rightarrow K_S^0 p K^-$ decays, Ξ_b^0 decays to both $K_S^0 p \pi^-$ and $K_S^0 p K^-$ final states, and the $\Lambda_b^0 \rightarrow D_s^-(K_S^0 K^-)p$ decay, and upper limits on their branching fractions are reported.

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1 Introduction

Studies of b baryon decays are at an early stage, with only a few known decay modes [1]. Most of these decays are of the Λ_b^0 , the lightest ground state b baryon. However, no three-body charmless hadronic final states had yet been observed. Conservation of baryon number means that searches for CP violation do not require flavour tagging, which is challenging at hadron colliders. With large data samples in the future, Dalitz plot analyses of charmless three-body decays can provide further sensitivity to CP violating observables. The LHCb detector [2] is a single arm spectrometer at the Large Hadron Collider. The data sample used corresponds to an integrated luminosity of 1.0 fb^{-1} . For more details about this analysis see Ref. [3].

2 Selection

The decay chain required is $\Lambda_b^0 \rightarrow K_S^0 p h^-$ with $K_S^0 \rightarrow \pi^+ \pi^-$, where h is a kaon or pion. Reconstruction of K_S^0 candidates is split into two categories, *long* and *downstream* candidates. Long candidates are K_S^0 candidates where the daughter tracks have hits in the vertex detector and tracking stations. Downstream candidates occur when the K_S^0 daughters do not have hits in the vertex detector. Boosted decision trees (BDTs) are used to separated signal decays from combinatorial background. The BDTs are trained separately for long and downstream candidates, using a simulated signal sample and high B mass sideband data for the combinatorial background. Particle identification requirements are applied to discriminate between pions, kaons and protons. Charmless decays ($\Lambda_b^0(\Xi_b^0) \rightarrow K_S^0 p h^-$) are separated from their charmed counterparts ($\Lambda_b^0 \rightarrow \Lambda_c^+ h^- (D_s^- p)$). The decay $B^0 \rightarrow K_S^0 \pi^+ \pi^-$ is used as a normalisation channel.

3 Fitting

The data is fitted using an extended unbinned maximum likelihood fit to the b baryon candidate invariant mass distribution, performed simultaneously to all decay modes. Signal peaks are modelled with the sum of a Gaussian and a bifurcated Gaussian, the combinatorial background is fitted by an exponential shape and the mis-identified backgrounds with a double Crystal Ball [4] function determined from simulation. The mass difference between the Λ_b^0 and Ξ_b^0 baryons is fixed to $168.6 \pm 5.0 \text{ MeV}/c^2$ [1]. The fit is shown in Figs. 1 and 2 for the charmless and charm modes, respectively. The signal yields are summarised in Table 1.

Table 1: Yields of the various decay modes from the simultaneous fit with statistical uncertainties.

Decay mode	Downstream yield	Long yield
$\Lambda_b^0 \rightarrow K_S^0 p \pi^-$	106.1 ± 21.5	90.0 ± 14.6
$\Lambda_b^0 \rightarrow K_S^0 p K^-$	11.5 ± 10.7	19.6 ± 8.5
$\Xi_b^0 \rightarrow K_S^0 p \pi^-$	5.3 ± 15.7	6.4 ± 8.5
$\Xi_b^0 \rightarrow K_S^0 p K^-$	10.5 ± 8.8	6.3 ± 5.6
$\Lambda_b^0 \rightarrow \Lambda_c^+ (\rightarrow p \bar{K}^0) \pi^-$	1391.6 ± 39.6	536.8 ± 24.6
$\Lambda_b^0 \rightarrow \Lambda_c^+ (\rightarrow p \bar{K}^0) K^-$	70.0 ± 10.3	37.4 ± 7.1
$\Lambda_b^0 \rightarrow D_s^- (\rightarrow K^0 K^-) p$	70.0 ± 10.3	37.4 ± 7.1

4 Results

Branching fractions are determined relative to $\mathcal{B}(B^0 \rightarrow K^0 \pi^+ \pi^-)$ and the known value [1] is used to determine the absolute branching fractions. Efficiency corrections and corrections due to the fragmentation fraction ($f_{\Lambda_b^0}/f_d$) are applied. The results are quoted for K^0 or \bar{K}^0 , according to the expectation for each

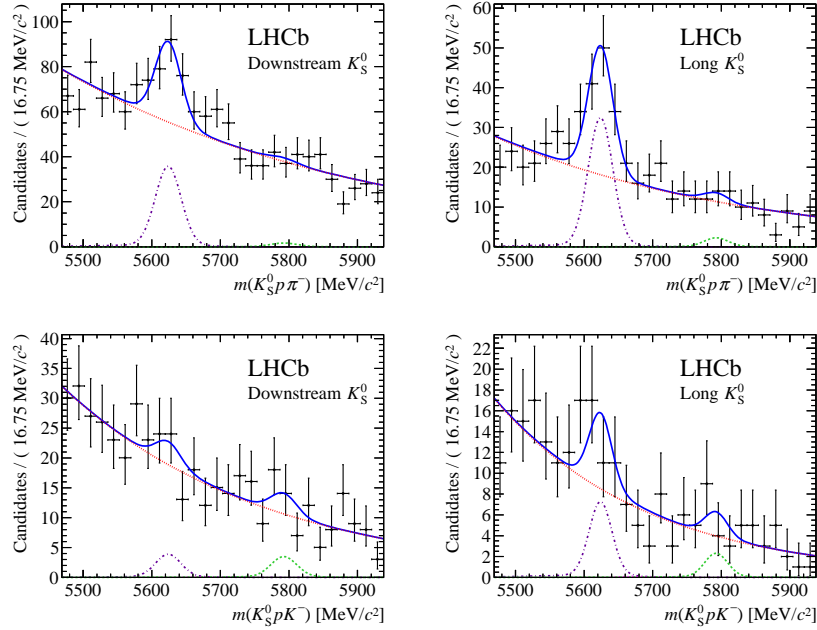


Figure 1: Fits to the b baryon candidate invariant mass distribution for (top) $\Lambda_b^0 \rightarrow K_S^0 p \pi^-$ and (bottom) $\Lambda_b^0 \rightarrow K_S^0 p K^-$ decays. The left (right) column shows downstream (long) K_S^0 candidates only. The visible shapes are the (blue) full fit, (violet) Λ_b^0 signal, (green) Ξ_b^0 signal and (red) combinatorial background.

decay

$$\begin{aligned}
\mathcal{B}(\Lambda_b^0 \rightarrow \bar{K}^0 p \pi^-) &= (1.26 \pm 0.19 \pm 0.09 \pm 0.34 \pm 0.05) \times 10^{-5}, \\
\mathcal{B}(\Lambda_b^0 \rightarrow K^0 p K^-) &= (1.8 \pm 1.2 \pm 0.8 \pm 0.5 \pm 0.1) \times 10^{-6}, < 3.5 (4.0) \times 10^{-6} \text{ at 90 \% (95 \% CL),} \\
f_{\Xi_b^0}/f_d \times \mathcal{B}(\Xi_b^0 \rightarrow \bar{K}^0 p \pi^-) &= (0.6 \pm 0.7 \pm 0.2) \times 10^{-6}, < 1.6 (1.8) \times 10^{-6} \text{ at 90 \% (95 \% CL),} \\
f_{\Xi_b^0}/f_d \times \mathcal{B}(\Xi_b^0 \rightarrow \bar{K}^0 p K^-) &= (0.6 \pm 0.4 \pm 0.2) \times 10^{-6}, < 1.1 (1.2) \times 10^{-6} \text{ at 90 \% (95 \% CL),} \\
\mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+ (\rightarrow p \bar{K}^0) \pi^-) &= (1.40 \pm 0.07 \pm 0.08 \pm 0.38 \pm 0.06) \times 10^{-4}, \\
\mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+ (\rightarrow p \bar{K}^0) K^-) &= (0.83 \pm 0.10 \pm 0.06 \pm 0.23 \pm 0.03) \times 10^{-5}, \\
\mathcal{B}(\Lambda_b^0 \rightarrow D_s^- (\rightarrow K^0 K^-) p) &= (2.0 \pm 1.1 \pm 0.2 \pm 0.5 \pm 0.1) \times 10^{-6}, < 3.5 (3.9) \times 10^{-6} \text{ at 90 \% (95 \% CL).}
\end{aligned}$$

For Λ_b^0 decays the uncertainties are statistical, systematic, plus those arising from the external inputs $f_{\Lambda_b^0}/f_d$ and $\mathcal{B}(B^0 \rightarrow K^0 \pi^+ \pi^-)$, respectively. For Ξ_b^0 decays the fragmentation fraction is unknown and the uncertainty from $\mathcal{B}(B^0 \rightarrow K^0 \pi^+ \pi^-)$ is negligible. The $\Lambda_b^0 \rightarrow \Lambda_c^+ h^-$ branching fractions can be determined more precisely since $\mathcal{B}(\Lambda_c^+ \rightarrow p \bar{K}^0)/\mathcal{B}(\Lambda_c^+ \rightarrow p K^- \pi^+)$ is better known than $\mathcal{B}(\Lambda_c^+ \rightarrow p K^- \pi^+)$, which dominates the uncertainty on $f_{\Lambda_b^0}/f_d$. Dividing the branching fractions by $\mathcal{B}(\Lambda_c^+ \rightarrow p K^- \pi^+)$ and the ratio of Λ_c^+ branching fractions gives

$$\begin{aligned}
\mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-) &= (5.97 \pm 0.28 \pm 0.34 \pm 0.70 \pm 0.24) \times 10^{-3}, \\
\mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+ K^-) &= (3.55 \pm 0.44 \pm 0.24 \pm 0.41 \pm 0.14) \times 10^{-4}.
\end{aligned}$$

The known value of $\mathcal{B}(D_s^- \rightarrow K^0 K^-)$ can be used to get

$$\mathcal{B}(\Lambda_b^0 \rightarrow D_s^- p) = (2.7 \pm 1.4 \pm 0.7 \pm 0.1 \pm 0.1) \times 10^{-4}, < 4.8 (5.3) \times 10^{-4} \text{ at 90 \% (95 \% CL),}$$

where the last uncertainty is from $\mathcal{B}(D_s^- \rightarrow K^0 K^-)$.

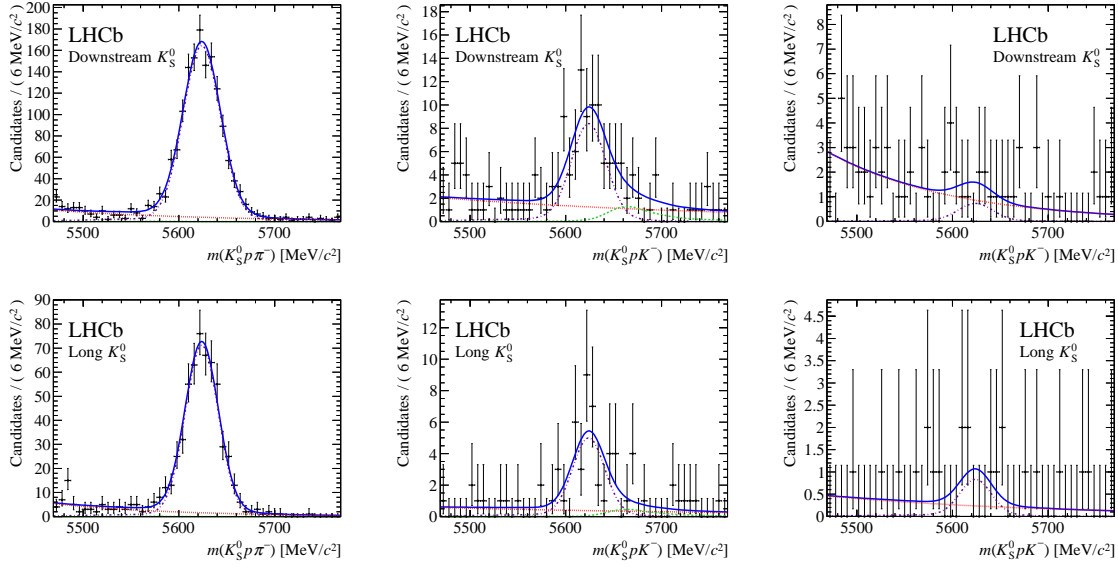


Figure 2: Fits to the b baryon candidate invariant mass distribution for (left) $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$, (middle) $\Lambda_b^0 \rightarrow \Lambda_c^+ K^-$ and (right) $\Lambda_b^0 \rightarrow D_s^- p$ decays. The top (bottom) column shows downstream (long) K_S^0 candidates only. The visible shapes are the (blue) full fit, (violet) Λ_b^0 signal, (green) cross-feed contributions and (red) combinatorial background.

The large $\Lambda_b^0 \rightarrow K_S^0 p \pi^-$ signal yield allows a measurement of the integrated CP asymmetry, defined as

$$\mathcal{A}_{CP}^{\text{RAW}} = \frac{N_{\bar{f}} - N_f}{N_{\bar{f}} + N_f},$$

where $N_{f(\bar{f})}$ is the signal yield for $\bar{\Lambda}_b^0(\Lambda_b^0)$ decays. Corrections are applied for detection (\mathcal{A}_D) and production (\mathcal{A}_P) asymmetries to give $\mathcal{A}_{CP} = \mathcal{A}_{CP}^{\text{RAW}} - \mathcal{A}_P - \mathcal{A}_D$. The corrections are taken from $\Lambda_b^0 \rightarrow \Lambda_c^+(\rightarrow p \bar{K}^0) \pi^-$ decays, which are expected to have negligible CP violation. The corrected value is

$$\mathcal{A}_{CP}(\Lambda_b^0 \rightarrow K_S^0 p \pi^-) = 0.22 \pm 0.13(\text{stat}) \pm 0.03(\text{syst}),$$

which is consistent with zero. The decay $\Lambda_b^0 \rightarrow K_S^0 p \pi^-$ is observed for the first time with a significance of 8.6σ , allowing a measurement of its integrated CP asymmetry. Limits are set for the other decays modes where the signal yields are not significant. This work opens up exciting possibilities to study such decays with large data samples in the future.

ACKNOWLEDGEMENTS

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